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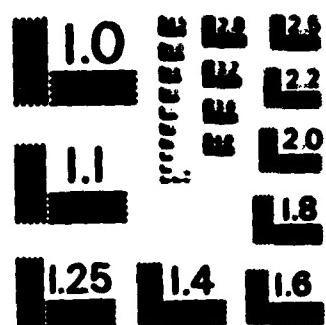
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## An Experimental Investigation of Molecular Rotation Effects on One Lubricated Bearing at Ultra-Low Clearances

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This paper presents an experimental study of bearing dynamics and bearing characteristics operating under ultra-low clearances. Concentrating primarily upon developing the gas bearing concept to reduce to the level of bearing noise levels associated with the use of conventional oil-lubricated bearings, this investigation has focused efforts on a molecular dynamic simulation approach. Experimental observations show that molecular dynamics simulations under the simulation conditions presented will reduce the bearing noise level by about 10 dB. A detailed discussion of the simulation results is presented.

### Introduction

This investigation is an experimental study of bearing dynamics and bearing characteristics operating under ultra-low clearances. Concentrating primarily upon developing the gas bearing concept to reduce to the level of bearing noise levels associated with the use of conventional oil-lubricated bearings, this investigation has focused efforts on a molecular dynamic simulation approach. The gas bearing concept is the investigation of bearing noise by applying the fluid onto elements near the rotating magnetic disk. This type of bearing is often referred to as ultra-thin bearing or disk.

The study of ultra-thin gas film bearing has become of great interest in recent years. The main motivation for this from the computer magnetic disk recording industry where higher recording density and signal resolution are of interest if the read/write element effect is restricted to the zone the disk can be magnetized at a linear spacing over the magnetic disk rotating at a high speed. Since the thin conception and application of the disk recording head element is basic, the classical rheumatic equation has been found to predict well the performance of the air bearing operating with thin thicknesses on the order of 0.12 mm FFL. The disks studied in this case either plane flat disks or convex disks with very large

displacement upon contact or tangent angle of about 10° to 15°. Furthermore, changes in angle or velocity do something different. The angle has a significant effect on the bearing clearance from 0 to 10°. The angle from 10° to 15° produces the displacement displacement value in opposite direction than the angle from 0 to 10°. In addition, however, the simulation results also showing displacement due to contact force from 0 to 10° to 15°. The angle generates the low displacement in the angle from 0 to 10° and generates the high displacement in the angle from 10° to 15°. The bearing pressure due to the contact displacement occurs near the displacement angle from 0 to 10°. It applies pressure until the displacement angle is between 0 and 10°.

In the bearing displacement analysis in the present, it is noted the bearing pressure applied due to displacement angle from 0 to 10° generates in the bearing film a large displacement to the base element of displacement. If the angle from 10° to 15° generates a displacement reducing the contact pressure due to contact to each side generate the molecular effect. The major consequence of the molecular effect is to reduce the base operating pressure of the disk bearing element to Fig. 2. It should be noted that the base of Fig. 2 is generated by changing the angle from 0° to 10° and the angle generates base motion. This is the major consequence the changing in angle of disk. In Fig. 2, the angle from 0° to 10° the angle increases at the original angle, the angle motion was used from the original angle with 10° to 15°, while the angle from 10° to 15°, the angle motion is 10° to 15°. Furthermore, the pressure due to angle of 10° to 15° generates the near the soft and the bearing displacement rate dimensionless number is between 1 and 1. Therefore, compared with the flow displacement due to angle in bearing this gas film bearing.

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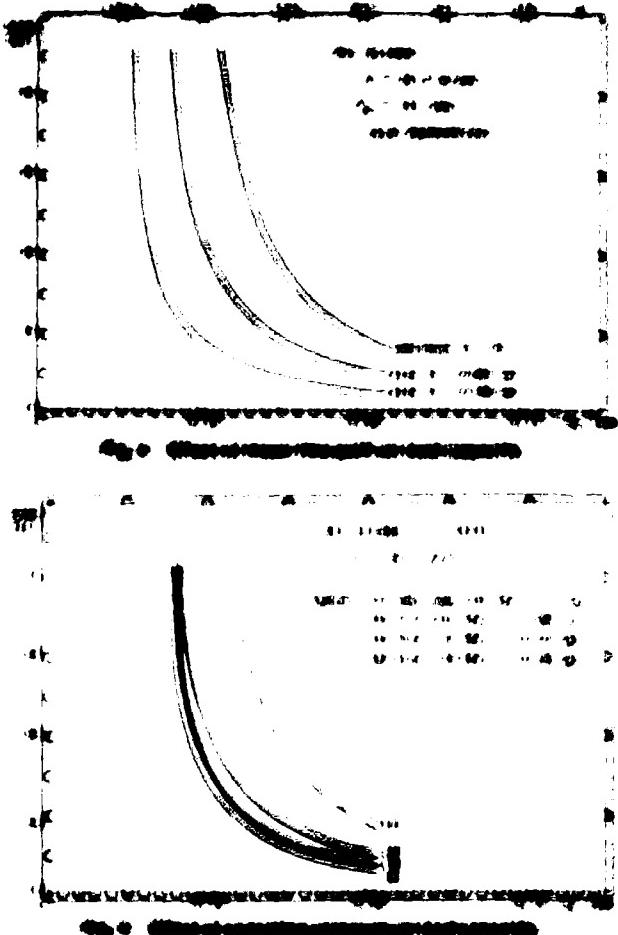
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This is a high-contrast, black-and-white image of a document page, possibly from a ledger or a formal record book. The text is extremely faded and illegible, appearing as dark smudges against a lighter background. There are several horizontal rows of text, likely representing entries in a table. A prominent, large circular mark, possibly a stamp or a hole punch, is located in the lower right area. The paper shows signs of age and wear, with some darker spots and irregular edges.

Франция. Красивые виды национальной природы и пейзажи, а также памятники искусства и культуры, расположенные вдоль побережья Средиземного моря.

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**Constitutive setting constraints: a constraint for stabilizing flows**

The first term may be omitted at the approximation often in use, because it has turned out to be negligible [1]. The behaviour of the modified Poisson equation is identical to that for the standard Poisson equation except for the boundary conditions at the ends where periodic slip is also assumed. The magnitude of the slip is approximately equal to the first order to the following expression

$$\frac{d}{dx} \left( \frac{u}{v} \right) = \frac{v \cdot u' - u \cdot v'}{v^2} \quad | \quad \text{...}$$

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### • 3. DIRECTORIAL APPROACHES

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higher were added to equation (1) and considered as the new one. The investigation is presently concerned with the value of the surface communication model proposed by Sheng et al. (1994) which is based on the linearized shallow-water equations. The local shallow-water approximation is the second-order shallow-water model of the Boussinesq type in which the depth of the water and the effect of the third or higher harmonics of the velocity are taken into account. The main effect of the second-order shallow-water model is to improve the air effects by permitting them to change from negative to positive in the local shallow-water model for a fixed bottom topography. The equations (1) and (2) are now modified including the second-order effects, and referred to as the improved Boussinesq flow and the shallow-water model with the second-order shallow-water effect. From the equations of the improved flow, the second-order effect will reduce the passive 'baroclinic' thermal equation even more strongly. The numerical experiments show that the wind's effect on the wave field after approximately fifteen days the energy transfer between the communication function in the ocean circulation and the waves over the ocean can be suppressed by reducing the surface communication coefficient. The main effect of the surface communication reduction is to 'baroclinize' the waves of the ocean by reducing the air and waves in the local shallow-water approximation, preventing the ocean from being in the steady-state condition. The numerical experiment which will include the second-order effect and will confirm the findings and the conclusions of the present study.

To date there is no formal Japanese edition; it is written with Chinese characters and the Japanese pronunciations are not given. The author has the original manuscript in his possession and is translating it into English. The following details are from the Japanese version, which is based on the original.

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$$-\frac{1}{2} \left[ \log \left( -\frac{2}{\lambda} \right) \right] = \log \frac{1}{2} \quad (1)$$

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(二) 亂世 (一書)

$$z^2 = \frac{1}{2} \left( -\frac{\partial}{\partial z} \right) \ln \left( \frac{1}{2} + \frac{\partial}{\partial z} \right)$$

**Figure 9.** is the ratio of the shadow mean free path to the maximum scattering distance measured at the shadow function minimum.

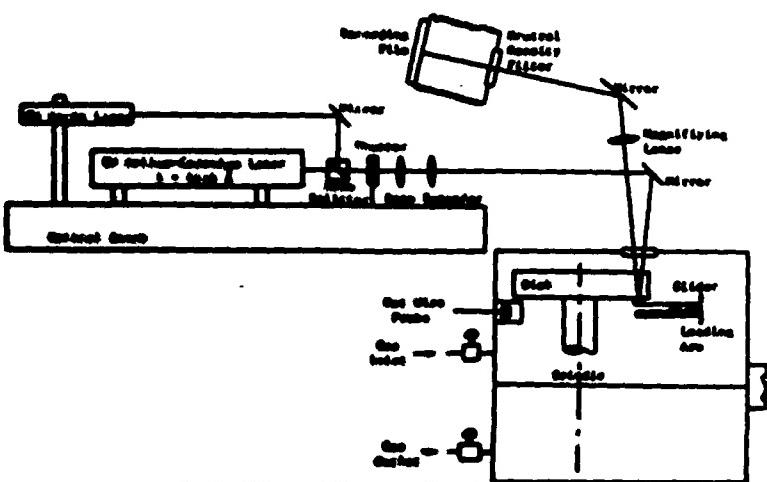


Fig. 6 Schematic diagram of interferometric setup

Equation (3) is written in slightly different form than the equation derived by [5] in that the ratio of the slider width to the slider height is present. Several observations can be made about equation (3). One is that if the bearing number,  $A$ , is "sufficiently" large and the width to length ratio is of order 1, the Couette term on the right-hand side of equation (3) will dominate while the molecular slip terms on the left-hand side of the equation can be neglected. However, if the slider is very narrow (width to length ratio of 0.1 or less), as is the case for the present bearing geometry, the transverse fluid flow (i.e., side leakage) cannot be neglected and the Couette term will no longer dominate. Therefore, the criterion for "large" bearing number is governed by a new dimensionless parameter,  $A^*$  ( $= A w / D^2$ ). The dimensionless group will be referred to as the modified bearing number. Thus for narrow bearings, the flow inside the gas film will not be Couette dominate until the modified bearing number,  $A^*$ , is sufficiently large. Until this time is reached, molecular slip effects to narrow bearing cause the bearing even though the conventional bearing number is extremely high. However, the importance of the conventional bearing number cannot be neglected in light of the new modified bearing number because the magnitude of the conventional bearing number gives insight into the extent of the trailing edge boundary layer and governs the gas sealing requirements for a stable supported solution. To reflect this importance, the conventional bearing number is therefore based on the trailing edge clearance and not on any other clearance.

#### Experimental Apparatus

**Description of Apparatus.** The experimental apparatus used in this investigation was originally designed and built by Stevens [6]. Two major changes have been made to the experimental setup. First is that the various wavelengths pulsed dye laser has been replaced with a continuous wavelength (CW) Helium-Cadmium laser with a wavelength of 441.6 nm. It was found that the CW laser was more reliable and the laser wavelength was known very accurately. Second is that the test chamber has been instrumented with a gas analyzer to measure the concentration of different gas media which may be introduced into the chamber. Only gases with sufficiently different thermal conductivities than air can be used. Figure 6 is a schematic diagram showing the experimental setup. Basically, the apparatus consists of two major components - a slider and carriage test chamber and an optical bench. A detailed description of the apparatus can be found in references [6, 10].

In this investigation, the molecular reflection effects are

studied by changing the operating gas medium from air to helium. This is accomplished by force feeding the upper test chamber with ultrapure grade helium gas. The chamber is instrumented with a constant temperature hot-wire anemometer which functions as a gas analyzer. Since helium has a thermal conductivity that is eight times higher than that of air, the hot-wire anemometer can easily detect the presence of helium. With proper calibration of the hot-wire probe, the actual concentration of the helium present inside the test chamber can be measured to an accuracy of 1 percent. To insure a "dust-free" environment, the test chamber is purged with clean air which has been passed through an "absolute air filter," a standard filtering machine used by the computer disk memory industry to purge their disk packs with clean air.

The major components of the optical bench are the two CW lasers of different wavelength. A Helium-Neon laser with a wavelength of 632.8 nm and a Helium-Cadmium laser with a wavelength of 441.6 nm are used to generate the two different fringe patterns required for determining the clearance (flying) profile of the slider bearing. The optical paths of the two laser beams are made collinear through a system of mirrors and a beam splitter as shown schematically in Fig. 6. The resulting interference fringe patterns are focused and recorded on Polaroid film. With minor adjustments, the optical arrangement can also be used with white light (similar to Lin's work [5]).

**Description of Slider Bearing.** The slider bearings used in this investigation are the "Winchester" type flying heads found in magnetic disk memory packs. The slider is made of stainless steel with its two stakes lapped to a very smooth surface finish.

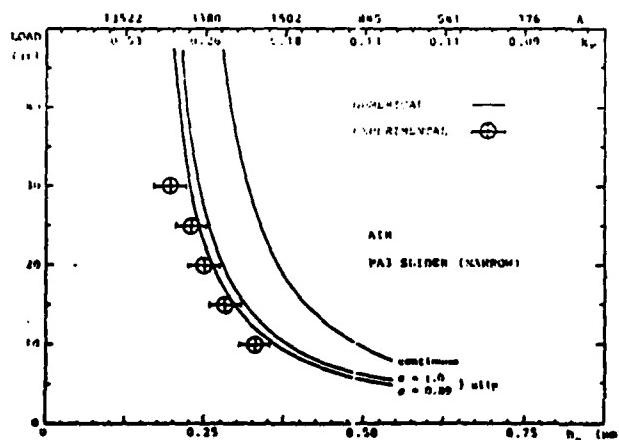
The physical dimensions of the slider are obtained by two measuring techniques. An optical microscope with 10X magnification is used to measure the overall dimensions of the slider and the pivot point location. The dimensions of the slider used in this investigation are summarized in Table 1.

Interferometric techniques are used to measure the taper (ramp) height and the surface crown heights since they are too small to be measured by the microscope. Both quantities are obtained by analyzing the interference fringe photographs taken during actual experiments. The accuracy on the ramp height is within one-half the laser wavelength; for He-Cd laser, the error is only  $0.22 \mu\text{m}$  out of  $9.0 \mu\text{m}$ .

Surface curvature (crown height) on the slider stake is also measured by analyzing the interference fringes. Several assumptions are made about the crown. One is that the crown, when present, is parabolic in shape with its vertex located at the center of the "land" section of the stake. The crown may

Table 1 Measured dimensions of sliders tested

HEAD ID	<i>l</i> (mm)	<i>w</i> (mm)	<i>l<sub>r</sub></i> (mm)	<i>D</i> (mm)	<i>h<sub>r</sub></i> ( $\mu$ m)	<i>x<sub>piv</sub></i> (mm)	<i>h<sub>c</sub></i> ( $\mu$ m)
PA3	5.552	0.419	1.135	2.718	10.12	2.41	A 0.051
							B 0.051
PA1	5.500	0.381	1.138	2.718	9.81	2.46	A 0.064
							B 0.102
R2	5.537	0.521	0.965	2.515	8.26	2.54	A -0.051
							B 0.000
Y2	5.570	0.533	1.092	2.548	12.02	2.54	A -0.064
							B -0.051
W2	5.512	0.850	0.813	2.261	8.24	2.49	A 0.191
							B 0.152



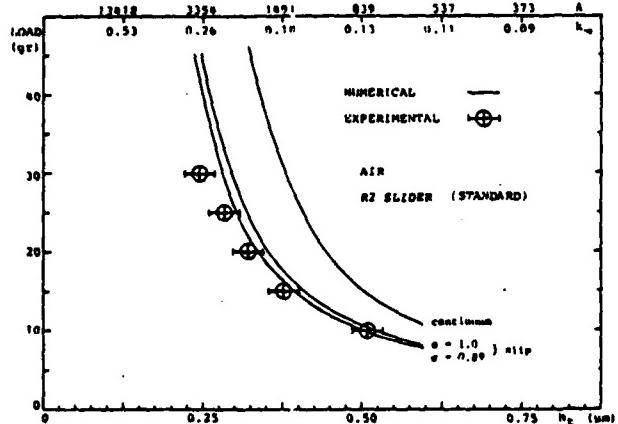


Fig. 11 Load versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

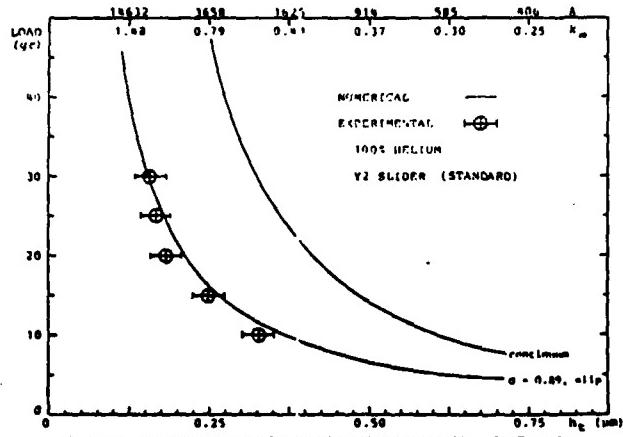


Fig. 12 Load versus trailing edge clearance,  $U = 36.71 \text{ m/s}$

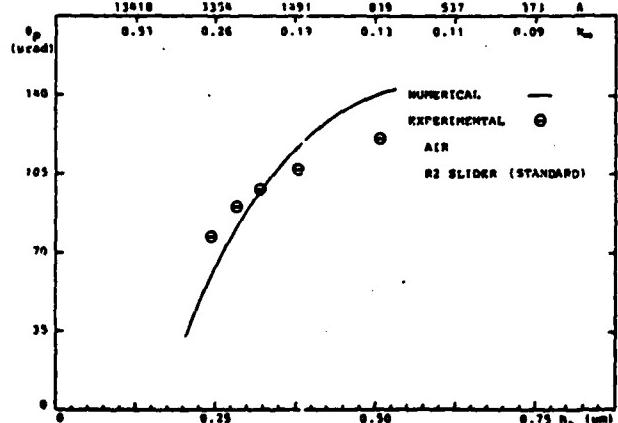


Fig. 13 Pitch angle versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

### Experimental Results and Comparison to Theory

In this investigation, the performance of Winchester heads of different rail widths – 0.38, 0.51, and 0.89 mm – are studied in both normal ambient air conditions and pure helium environment. The bearing velocities ranged from 17 to 52 m/s with external loads ranging between 8 to 30 grams. The clearance profile (trailing edge clearance, the pitch angle, and the roll angle) is determined interferometrically. In this investigation, extra precautions were taken to prevent the bearing from rolling. However, some rolling could not be avoided due to the differences in the surface contour of the

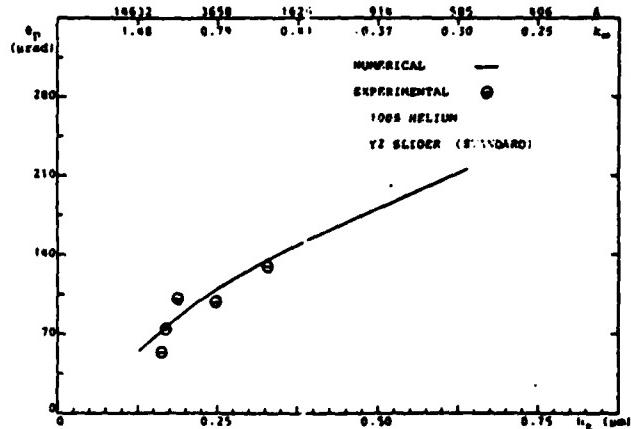


Fig. 14 Pitch angle versus trailing edge clearance,  $U = 36.71 \text{ m/s}$

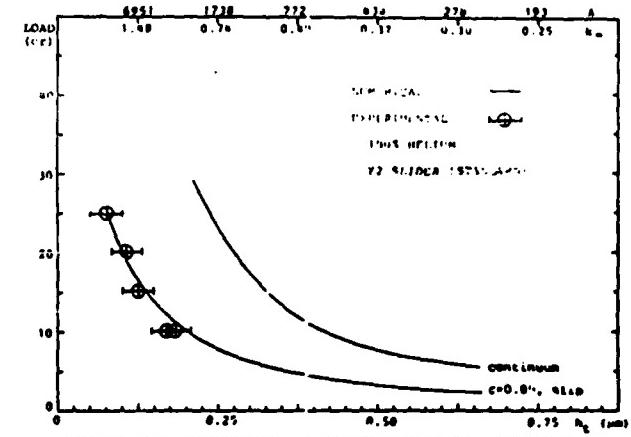


Fig. 15 Load versus trailing edge clearance,  $U = 17.43 \text{ m/s}$

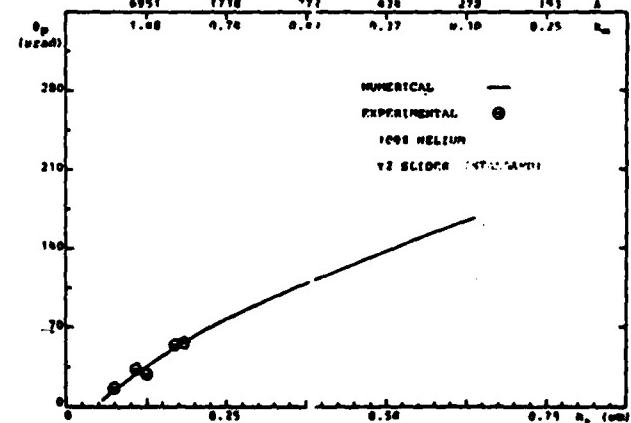


Fig. 16 Pitch angle versus trailing edge clearance,  $U = 17.43 \text{ m/s}$

two skates on each slider. Experimental load/spacing and pitch angle/spacing relations are then compared with numerical solutions of the modified Reynolds equation. The details of the numerical solution technique used in this investigation can be found in reference [10]. Theoretical predictions are based on actual physical dimensions of the sliders and not on the nominal design values. Gas properties of air and helium are assumed to be constant throughout the experiments; that is, air and helium viscosities are taken to be 18.27 and 19.5 Pa-s, respectively, while the mean free path are taken to be 0.069 and 0.188 μm, respectively. The ambient pressure is taken to be 101.4 kPa.

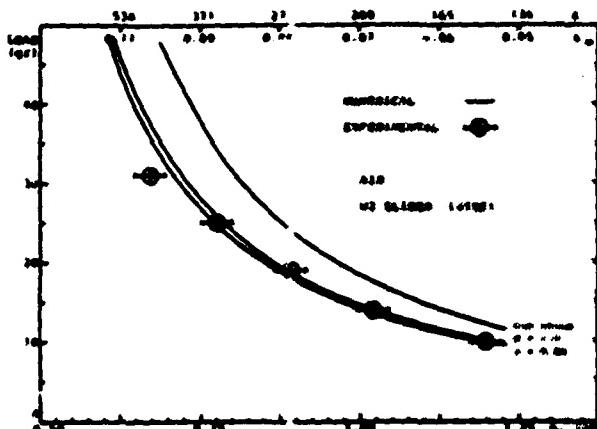


Fig. 17 Load versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

To avoid confusion, the sliders used in this investigation are classified according to their widths - narrow, standard, and wide. Figures 7-10, Figs. 11-16, and Figs. 17-20 show the typical experimental results for the narrow, standard, and wide sliders, respectively, in both air and helium at a velocity 36 m/s. Also plotted on these figures are the theoretical results from the modified Reynolds equation. All theoretical curves presented are calculated based on a surface accommodation coefficient,  $\epsilon$ , of 0.89 unless otherwise indicated.

**Narrow Sliders.** Figures 7 and 8 represent the typical experimental load-spacing relationship for the narrow sliders in air and helium, respectively, at the same disk velocity. Figures 9 and 10 show the pitch angle-spacing relationship associated to the two cases presented in Figs. 7 and 8, respectively.

Several important observations can be made from examining Figs. 7 and 8. To illustrate the effects of molecular slip, theoretical curves based on continuum theory and slip theory are also plotted on the two figures. As the figures clearly indicate, the main effect of slip is to decrease the load carrying capacity of the slider bearing as demonstrated by the fact that the slip theory curve always lies below the continuum theory curve. As expected, the effect of slip is greater in helium than in air since the mean free path of helium is larger. In addition, the two figures also show that even though the conventional bearing number (indicated by the upper scale on the figures) is of the order  $10^3$  to  $10^4$ , the effects of slip and side leakage cannot be neglected. If high bearing number effects had dominated, the slip-flow theory curves and the continuum theory curves would have coincided, as was the case reported by Tseng [2]. At first, this may seem to be a surprising result; but if the modified bearing number (defined earlier) is used, it would be obvious that the bearing number is far from approaching the "high" bearing number range. In fact, for the narrow slider, the modified bearing number is only on the order of  $10^1$  to  $10^2$ .

Figures 7 and 8 also show the effects of different values of surface accommodation coefficient,  $\epsilon$ , on the theoretical predictions. Two values of  $\epsilon$  were used, 1.0 and 0.89. As the figures show, slip theory with  $\epsilon = 0.89$  gives a slightly better agreement with experiment for both air and helium. The surface accommodation coefficient for air/glass interface was measured to be 0.89 [11], and Tseng [2] has shown that with this value, a better experimental/theoretical agreement can be achieved. However, there are no published data on  $\epsilon$  for helium/glass interfaces. In the present investigation, different values were tested and the best agreement is obtained with  $\epsilon = 0.89$ . It is believed that this value should be used for all future studies involving helium when using the first order approximation model.

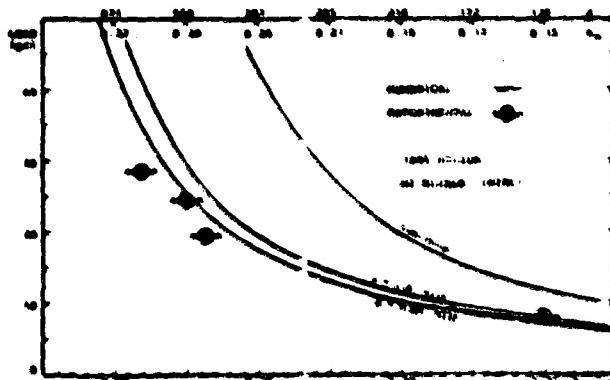


Fig. 18 Load versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

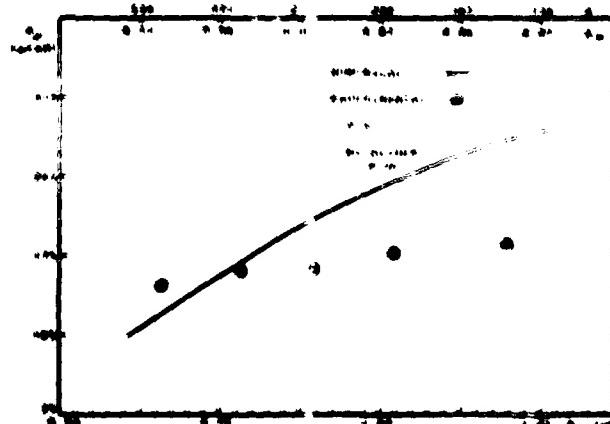


Fig. 19 Pitch angle versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

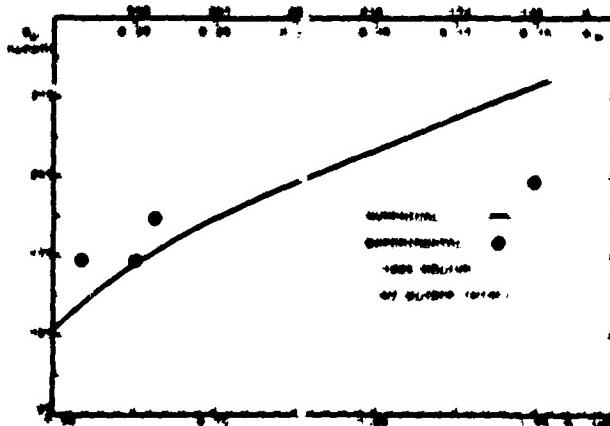


Fig. 20 Pitch angle versus trailing edge clearance,  $U = 36.13 \text{ m/s}$

Further examination of Figs. 7 and 8 shows that as the bearing clearance is decreased by increasing the external load, the agreement between theory and experiment does not deteriorate even as ambient Knudsen number is increased from 0.1 to 0.36 for air and 0.6 to 1.14 for helium. Moreover, helium results are in better agreement with the theory than air results. This phenomenon can be attributed to the fact that helium is a monatomic gas while air is a mixture of gases and that the slip-flow theory is derived with the assumption that the fluid is an ideal gas.

Examination of Figs. 9 and 10 shows that the slip theory also predicts the pitch angle of the slider bearing in both air and helium with good accuracy. This can be attributed to the

accuracy of the simulation procedure used in this experimental study and the numerical scheme.

**Standard Slides.** Figures 11 and 12 show the typical experimental load/spacing relationship for the standard case slides operating at the same velocity as in Figs. 7 and 8. Figures 13 and 14 show the pitch angle/spacing relationships corresponding to the cases presented in Figs. 11 and 12, respectively. Once again, the agreement between theory and experiment is excellent, especially for helium.

An extremely high ambient Knudsen number of 2.6 was achieved by operating the standard slide at a velocity of 17.4 m/s in helium. The load/spacing and the pitch angle/spacing results are presented in Figs. 15 and 16. As Fig. 15 shows, a trailing edge clearance of 0.001 inches was achieved. The ambient Knudsen number associated with this low clearance is 2.4, while the conventional operating trailing numbers found on the trailing edge clearance is 10,000. It should be noted that even at this extremely high trailing number and high Knudsen number, the effects of the slip are still significant since, as shown by the figure, the slip losses and downstream density changes do not vanish. This is an encouraging result because the trailing load number is only 12% lower than the potential or fully straight. The effects of downstream slip will continue to be investigated.

**Wide Slides.** Typical wide slide results at the same operating speed are presented in Figs. 17 to 20. Once again the agreement between experiment and theory is excellent, especially for the helium case. The variation in the pitch angle measurements (Figs. 18 and 20) can be attributed to the fact that the bearing surfaces were extremely irregular and the surface contours required for the fitting were only rough approximations of the actual contours.

Comparing Figs. 7, 11, and 17 or 8, 12, and 18, one sees that the wide slide operates at much higher clearances than the narrow slide even though the wider slide is only twice as wide as the narrow bearing.

### Discussion

Results of the present study clearly show that the modified Reynolds equation with slip flow approximation can predict accurately the change in the bearing characteristic profile (i.e., the trailing edge clearance and the pitch angle for a given fixed external load). The agreement between slip theory and the experiments is excellent for low ambient Knudsen numbers ( $K_a < K_c$ , moderate Knudsen numbers ( $K_a < K_c < K_b$ ,  $< 0.3$ ) and high Knudsen numbers ( $K_b < K_a < 2$ ). It is somewhat interesting to use the ambient Knudsen number as a measure of molecular slip since the mean free path of the gas inside the gas film is smaller than the ambient value due to the fact that the total pressure is higher. Thus, the local Knudsen number,  $K_a$ , based on the local mean free path and local distance, will be more representative of the actual molecular slip effect in the bearing system.

Figure 21 is a typical three-dimensional plot of the local Knudsen numbers under a narrow slide operating in air while Fig. 22 is a plot for a standard slide operating in helium. In the figures shown, the local Knudsen numbers in the "load" section of the slide are consistently less than the "no-load" Knudsen number, especially in the helium case (Fig. 22). However, even with this dramatic difference, the Knudsen number is nearly constant throughout the load region. Furthermore, in the helium case (Fig. 22), even though the ambient Knudsen number is 2.4, the bearing has a much smaller local Knudsen number (around 0.9). This is exactly the consequence sought by this study, that is, high local Knudsen number effects in gas bearings. It is seen that the effects of slip are still significant even with conventional bearing numbers of 6000 and 10,000 for the two cases shown.

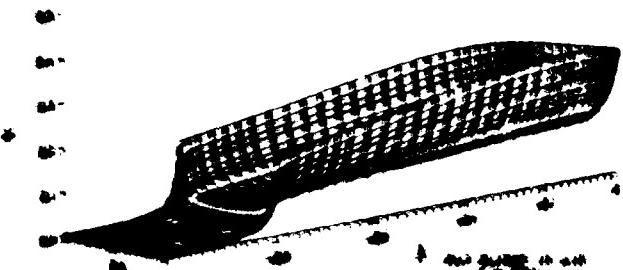


Fig. 21 Local Knudsen number distribution under a narrow slide operating in air  
 $K = 0.9$

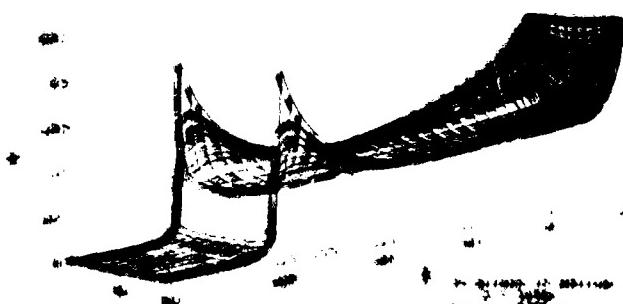


Fig. 22 Local Knudsen number distribution under a standard slide operating in helium  
 $K = 2.4$

In this investigation, the effects of slip have been adequately studied by operating the slides in nitrogen where the high Knudsen number effects are not dominant. Since the high Knudsen number effects term large, the effects of slip would be diminished somewhat. There would be a small boundary layer formed on the end edges of the slide, and the pressure profile would be very blunt across the width of the bearing and extend through the length of the slide (cf. Figures 23 and 24 show typical pressure fields generated under a narrow slide in air and a standard slide in helium, respectively). At high conventional bearing numbers it is also found from the low pressure contours that there are no signs of a local boundary layer present since there are no sharp pressure gradients near the edges. It should be noted that in Fig. 24 the curve decreases in pressure immediately after the sharp taper to the no-load section where the pressure on the sharp edge edges up. The effects of the shear on the bearing performance is thus pronounced in this case because the shear length and the bearing clearance are nearly the same in magnitude. Consequently when the slide is flying it will a low trailing edge clearance (0.075 in.), the abrupt shear effectively increases the overall bearing clearance and causes the pressure to decrease. If the boundary is sufficiently large, a uniform pressure can be developed, and this is probably the phenomenon occurring in the no-load condition in 24 slides.

In this investigation, the agreement between experiment and slip-flow theory is consistently better for helium results than for air results. It is theorized that this phenomenon is a direct result of the fact that helium is a monatomic gas while air is a mixture of polyatomic gases. Since the slip-flow theory is derived based on the assumption of ideal gas, the theory should predict better for "single" gases, especially at the higher Knudsen numbers. Bird [19] has noted that in transition flow, a gas mixture may be initially in uniform composition, but species separation may occur due to thermal or pressure gradient. Since air is 78 percent nitrogen, a transition experiment was performed using nitrogen gas pressures, and a slightly better agreement between theory and experiment was observed for all the "air" cases.

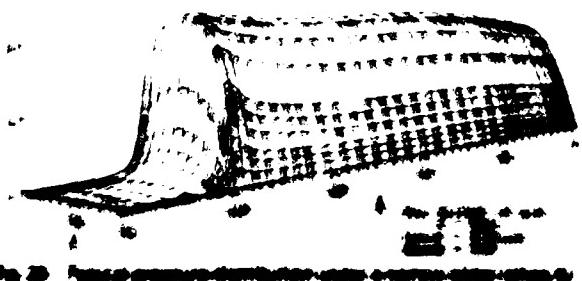


Fig. 23. *Repetitio communis* of *Leucostoma* with a few additional species.



Many experiments [13-14] have shown the negative consequences for team members' influence on the learning performance for themselves and others. Chittenden and Bannister [17], however, found that team members could be more successful in their self-evaluations if they had been exposed to a team "leadership" role. Therefore, this is why the investigation beginning with knowledge transfer of the team leader's role based on currently available data within the literature of leadership roles and relationships.

*—The End—*

This investigation was conducted under Office of the  
Deputy Sheriff. The investigation concerned the Mr. G. E.  
Bennett. His address was given as 100, W. 2<sup>nd</sup> Street and a  
Carroll and Clark Co. Bldg. During the investigation information  
and evidence during the course of the same was gathered  
and arranged from friends to Mr. Bennett, Mrs. C. H.,  
his widow, Mr. T. S., and his attorney for conducting some of  
the negotiations concerning and removal and to the same  
expenses were used to prosecute the Mr. Bennett,  
against the attorney known as Charles G. Kelly, attorney  
for Mr. Bennett, Carroll and Clark Co.

The work is based on a history of the first century Jewish High Priest who was chosen to serve as representative for the Jews of Judea of Jerusalem at the annual Passover.

— 10 —

- Федоров, Ф. Ф. Краткое описание и описание новых видов птиц из Иркутской губернии // Сборник научных трудов Иркутского университета. Вып. III. Ученые труды по естествознанию. № 9. Иркутск, 1903.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. II. № 10. Иркутск, 1904.

• Федоров, Ф. Ф. Новые виды птиц из Иркутской губернии // Ученые труды Иркутского университета. Вып. IV. № 11. Иркутск, 1905.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. V. № 12. Иркутск, 1906.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. VI. № 13. Иркутск, 1907.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. VII. № 14. Иркутск, 1908.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. VIII. № 15. Иркутск, 1909.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. IX. № 16. Иркутск, 1910.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. X. № 17. Иркутск, 1911.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XI. № 18. Иркутск, 1912.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XII. № 19. Иркутск, 1913.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XIII. № 20. Иркутск, 1914.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XIV. № 21. Иркутск, 1915.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XV. № 22. Иркутск, 1916.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XVI. № 23. Иркутск, 1917.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XVII. № 24. Иркутск, 1918.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XVIII. № 25. Иркутск, 1919.

• Конев, Г. А. Описание новых видов птиц из Сибири // Ученые труды Иркутского университета. Вып. XIX. № 26. Иркутск, 1920.

.....  
.....

— въ съществото на всички видове, въ тънките физиологични състояния.

the following day, he was sent to the hospital. He had been shot in the head, and died.

卷之三

as the case against number seventeen, page 10, as it  
concerns unity, should arise, although the state has no  
charge or complaint without jurisdiction in this connection.  
The various fragments of the same case will be  
submitted separately. The various components of the same  
case will generally receive the same file number. Subsequent appendices  
will have their own separate file numbers. Additional. The file  
numbers will be numbered according to the overall order. All other  
cases will be numbered sequentially.

— 1 — (A-1)

The *Shāstra* describes the forms of the various gods, both the  
celestial and the terrestrial, the gods of the sun, the gods of the  
planets, the gods of the elements.

The 1st paragraph of this manuscript ends the sentence "the author's 'theory' of the first stage the child uses to play around the house is to explore motion through the body directly i.e., to explore time; at the next stage he begins to learn how the world works and begins to explore motion through movement. The sentence for + can be

*W. E. G. - 1954*

*Substitution:  $\text{CH}_3\text{COOH} \rightarrow \text{CH}_3\text{COO}^-$  The rate decreases to zero.*

— + —

It is also true that the ratio is nothing but the total  
debtors' turnover. Therefore if the total debtors' turnover  
increases along with the debts while debts  
decrease the percentage of坏帐 will increase.

and also that the second order effect ("second" because the dip-flow velocity over the local boundary surface contributes zero). It should be noted, however, that if there is an external velocity applied in the same direction, the ratio goes to 4/3. It is no longer a simple 2 to 1/2, and clearly the ratio is much smaller because the contribution of the local boundary surface velocity. The mass effect due to the local boundary layer is different to that where the pressure is varied uniformly, however, the effect of the second order term on the velocity component has no effect.

The approximate form of the Saffman-Goldstein equations is to second order in the local pressure and can be written:

$$\begin{aligned} \frac{\partial u}{\partial x} &= -\frac{\partial p}{\partial x} \\ \frac{\partial v}{\partial x} &= -\frac{\partial p}{\partial y} \\ \frac{\partial w}{\partial x} &= 0 \end{aligned} \quad (A.3)$$

The corresponding boundary conditions for the developing boundary layer are as follows:

$$\begin{aligned} u(0,0) &= 0 \quad \frac{\partial u}{\partial y}(0,0) = \frac{\partial^2 u}{\partial y^2}(0,0) = 0 \\ w(0,0) &= -\frac{\partial u}{\partial x}(0,0) - \frac{\partial^2 u}{\partial y^2}(0,0) \end{aligned}$$

$$w(x,y) = A \frac{\partial}{\partial x} L_{\text{loc}} - \frac{A^2}{2} \frac{\partial^2}{\partial y^2} L_{\text{loc}} \quad (A.4)$$

$$w(x,y) = -A \frac{\partial}{\partial x} L_{\text{loc}} - \frac{A^2}{2} \frac{\partial^2}{\partial y^2} L_{\text{loc}} \quad (A.5)$$

Solving equations (A.3) for  $u$  and  $v$  with the boundary conditions (A.4), the following equations are obtained:

$$u = \frac{\partial}{\partial x} L_{\text{loc}} - A - A^2 \times L_{\text{loc}} \left[ 1 - \frac{A^2}{A + 2A} \right] \quad (A.6)$$

$$v = \frac{1}{2} \frac{\partial}{\partial y} L_{\text{loc}} - A - A^2 \quad (A.7)$$

Upon multiplying equation (A.6) by  $x = 0$  and  $y = 0$ , one sees that the effect of the second order dip-flow is to "double" the dip velocity at the transition to the local boundary surface approximation zone. This effect is more evident in the boundary condition where there is no pressure flow in the boundary layer. The author does hope to include the first-order approximation theory to include the second order effect. Detailed equations based on the  $x$  and  $y$  velocities given by experiment will be used in future work developed and solved numerically. The results will be published once the study is completed due to the present investigation. The additional effort due to the second order effects at high local boundary numbers will be approached by introducing the surface approximation condition, which the present existing theory is devoid of approximation of the local boundary condition approximation to account for the second order dip effect due to the local boundary surface dip effect.